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Right Whale Diving and Foraging Behavior in the Southwestern Gulf of Maine

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LONG-TERM GOALS

Mitigation of a variety of anthropogenic threats to endangered baleen whales depends on information about how the whales use the water column. For example, reducing ship strike risk requires an understanding of how much time whales spend at the surface, and mitigating fishing gear entanglements by ground lines requires an understanding of how often and why whales might dive near the bottom. My long-term goal is to characterize baleen whale foraging behavior by studying diving behavior with respect to both the vertical/horizontal distribution of their prey and oceanographic features and conditions (e.g., mixed layer, stratification, turbulence). This approach will allow me to characterize not only where in the water column the whales feed, but also where the prey are located, why the prey are organized as they are, and how the whales respond to variability in prey distribution and oceanographic conditions. By using this same approach to study several baleen whale species, comparisons between species will ultimately be possible to address fundamental questions about foraging ecology (e.g., variability in foraging strategy induced by morphological constraints and/or prey species/behavior) as well as about differential rates of interaction with human activities.

OBJECTIVES

The seriously endangered North Atlantic right whale is particularly vulnerable to ship strikes and fishing gear entanglements, and there is an urgent need for information about how right whales use the water column to develop strategies to mitigate these anthropogenic threats. Moreover, the right whale sits atop a relatively simple food chain consisting only of phytoplankton, copepods, and whales that can serve as a convenient model to study trophic interactions in the marine environment because both predator and prey can be monitored with available technologies (e.g., animal-mounted archival tags, video plankton recorder). From 2004-2010, we conducted research on the diving and foraging behavior of North Atlantic right whales in the southwestern Gulf of Maine (Great South Channel) by attaching tags to the whales, tracking their movements, and simultaneously and repeatedly sampling the water column to measure physical properties (temperature, salinity), biological properties (chlorophyll fluorescence) and prey distribution (after Baumgartner and Mate 2003). The current study seeks to analyze and publish these data. Specifically, my objectives are (1) to characterize the diving and foraging behavior of right whales in this important springtime habitat, (2) to investigate the

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biological and physical oceanographic processes that promote the thin, aggregated layers of copepods upon which the whales feed, and (3) to assess the risks posed to right whales by ships and fishing gear based on their foraging behavior.

APPROACH

Tagging, tracking, and sampling around right whales was accomplished with two vessels: an oceanographic vessel and a small, rigid-hulled inflatable boat (RHIB). After right whales were encountered, the RHIB was deployed from the oceanographic vessel (Figure 1a). Right whales were approached in the RHIB and suction-cup mounted archival tags were attached to the whales from this boat using a 9 m pole (Figure 1b,c). The tag consists of a time-depth recorder, pitch and roll sensors, a VHF radio transmitter, and a high-frequency acoustic transmitter. After successful deployment, the tagged whale was actively tracked via a high-frequency acoustic transmitter incorporated in the tag using an acoustic receiver and a hand-held directional hydrophone carried in the tagging boat. The tagging boat remained near the tagged whale at all times to collect identification photographs, behavioral information, fecal samples (if available), and to record the whale's surface locations. Upon resurfacing after each long dive, the whale's exact resurfacing position was recorded by the tagging boat using a global positioning system (GPS) receiver. This position was then relayed via radio to the oceanographic vessel and the ship moved to that position to deploy our vertical profiling instrument package (Figure 1d), which consists of a conductivity-temperature-depth (CTD) instrument, chlorophyll fluorometer, optical plankton counter, and video plankton recorder. Tracking and sampling with the instrument package continued until the tag detached from the whale, floated to the surface, and was recovered. The tag incorporated a corrosive release mechanism that allowed detachment after 1-3 hours.

The analysis of these data will focus on the following:

- Documenting the strong relationship between right whale dive depths and the vertical distribution of their prey, *Calanus finmarchicus*
- Investigating the physical and biological factors that influence the vertical distribution of *C. finmarchicus* (e.g., phytoplankton distribution, stratification, water mass associations at mid-depth, bottom mixed layer)
- Documenting bottom feeding by tagged right whales using short deployments where the tag was knocked off; we will use the pitch and roll data collected by the archival tag to determine the orientation of the whale during bottom feeding
- Comparing the abundance of *C. finmarchicus* in the Great South Channel with other similarly sampled habitats (e.g., Bay of Fundy, Roseway Basin, Jefferys Ledge) to determine the relative importance of the Great South Channel (from our preliminary analyses, it appears that the Great South Channel may have, by far, the highest abundances of *C. finmarchicus* than in any other right whale habitat)
- Characterizing the risk posed to right whales by ships and fishing gear when engaged in particular feeding behaviors.

A single paper will be produced by this analysis; the working title of this paper is "Right whale foraging ecology in the western Gulf of Maine," and it will complement a similar earlier paper by

Baumgartner and Mate (2003) entitled "Summertime foraging ecology of North Atlantic right whales". We have conducted a significant amount of research on the ecology of North Atlantic right whales, sei whales, and *Calanus finmarchicus* in the Great South Channel since 2004 (Baumgartner and Fratantoni 2008, Baumgartner et al. 2008, Tarrant et al. 2008, Patrician et al. 2009, Baumgartner et al. 2011), and this publication is a critical part of this ongoing research program designed to understand the environmental factors that influence baleen whale distribution and behavior.

WORK COMPLETED

This project has just recently begun, and only preliminary results are available (described below).

RESULTS

During 2004-2010, we tagged 19 whales in the Great South Channel with attachment times of 45 minutes or longer (Figure 2). As in previous studies, we found that the zooplankton community near right whales was dominated by late-stage *Calanus finmarchicus*. We observed significant variability in diving behavior, including feeding at the surface, mid-water, and at the bottom (Figure 3). Surface and near-surface feeding are commonly reported in the Great South Channel, so we were surprised to observe regular near-bottom feeding. We discovered highly concentrated near-bottom aggregations of *C. finmarchicus* (within 1-2 m of the bottom) that have never before been described in the Gulf of Maine. After observing bottom feeding in 2005, we modified our profiling instrument package to be capable of sampling *C. finmarchicus* within tens of centimeters of the sea floor.

During these same tagging cruises in 2005-2007, we conducted studies of the diel vertical migration (DVM) behavior of late-stage *C. finmarchicus* (Baumgartner et al. 2011). During each study, we deployed our vertical profiling instrument package at half-hour intervals for 24-48 hours at anchor stations in the Great South Channel while simultaneously conducting daytime surveys of baleen whale abundance in proximity to the ship. The goal of our DVM studies was to investigate the oceanographic factors that may influence DVM behavior and to elucidate the effect of DVM on (1) advection and retention of *C. finmarchicus* in the Great South Channel, (2) the occurrence of right and sei whales, and (3) right whale foraging behavior. We observed considerable variability in the DVM behavior of *C. finmarchicus*: sometimes DVM was quite strong such that most *C. finmarchicus* migrated to depth during the day and to the surface at night (e.g., Figure 4), whereas at other times, only a small portion of the population migrated while the majority of copepods remained at the surface during the day (Baumgartner et al. 2011). We hypothesize that right whales faithfully track these changes in distribution, such that when DVM behavior is strong (i.e., most copepods are migrating), near-bottom feeding during the day is prevalent, whereas when DVM behavior is weak, right whales can exploit daytime near surface concentrations of *C. finmarchicus*. In 2006, we observed evidence of this hypothesis; we tagged a right whale 6 hours after completing a DVM study during which migration behavior was very strong (Figure 4). The resulting dive data from the tagged whale (Figure 3e) indicated that it was engaged in daytime bottom feeding. Had we been able to track this whale's behavior into the following evening, we predict it would have switched to near-surface feeding as the copepods migrated from near the bottom to the surface at dusk.

IMPACT/APPLICATIONS

This work will directly help efforts to mitigate the effects of anthropogenic activities on baleen whales by characterizing where in the water column right whales feed and why the prey are organized as they

are. Ultimately, our ability to predict or even forecast right whale distribution will hinge on a fundamental understanding of right whale foraging behavior and how that behavior varies with changes in copepod behavior and distribution.

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Figure 1. Methods used for the tagging study, including (a) R/V* Boo Radley*, our tagging boat, (b) approach on two humpback whales illustrating the use of the 9 m long tagging pole, (c) successful tagging of a North Atlantic right whale, and (d) deployment of the vertical profiling instrument package.

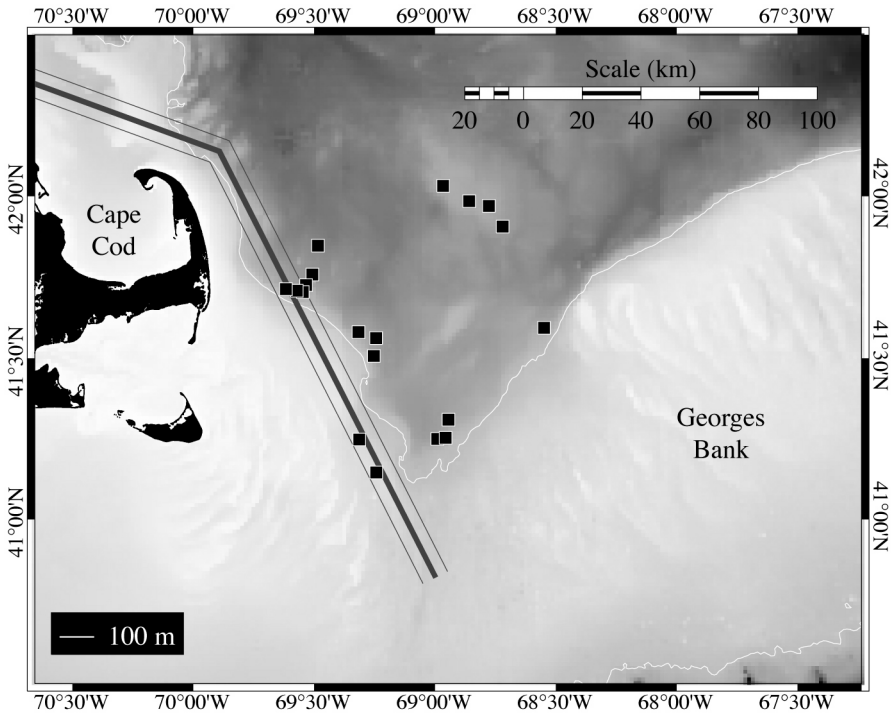

Figure 2. Study area in the Great South Channel between Cape Cod and Georges Bank in the southwestern Gulf of Maine. Black squares indicate locations where right whales were successfully tagged during 2004-2010. Water depth is shaded in gray (dark shades indicate deeper water), and the figure also includes the Boston shipping lanes.

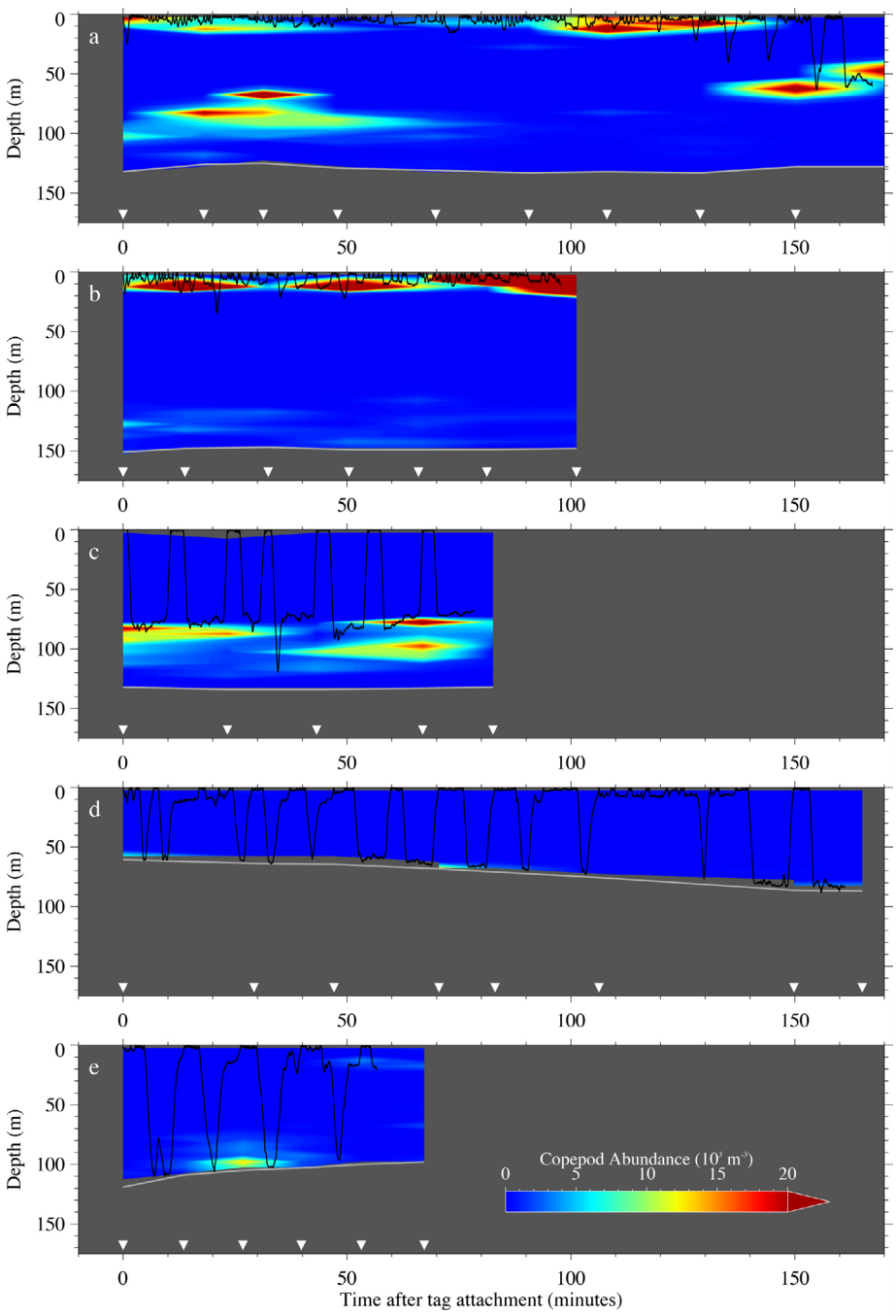

Figure 3. Examples of North Atlantic right whale diving and foraging observations in the Great South Channel from archival tags and collocated environmental sampling. Dive profiles of individual whales are shown as a black line, the sea floor is shown as a gray line, the abundance of copepods is shown in color, and the inverted triangles depict times when the profiles of copepod abundance, temperature, salinity, and chlorophyll fluorescence were collected. Note the range of behaviors observed, from surface feeding (a, b), mid-water feeding (c), and bottom feeding (d, e).

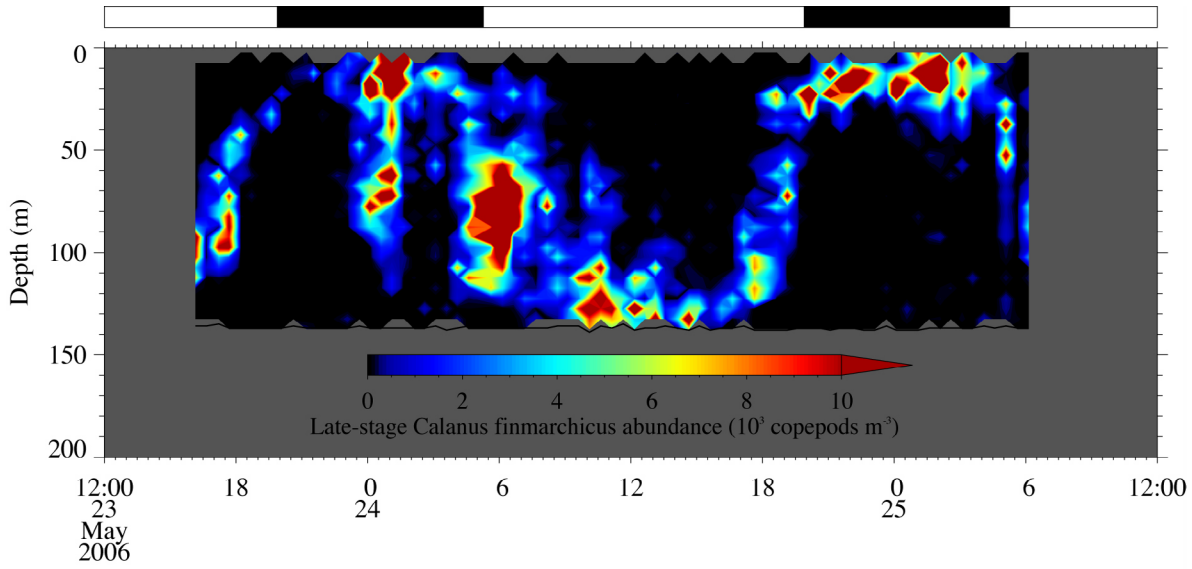

Figure 4. Results of one of the diel vertical migration behavior studies conducted May 23-25, 2006 in the Great South Channel in proximity to right whale tagging activities. Half-hourly observations of the vertical distribution of late-stage Calanus finmarchicus (primarily stage C5) were collected with the optical plankton counter at an anchor station. Colors indicate the abundance of C. finmarchicus, and the black and white bars at the top of the plot indicate night and day periods, respectively. Note that these data were collected within 6 hours and 2 km of the data shown in Figure 3e; these observations suggest that daytime bottom feeding by right whales is strongly influenced by copepod diel vertical migration. Data from Baumgartner et al. (2011).